FREQUENCY CALLIBRATION USING HF WWV

INTRODUCTION

If you've always wanted a stable, accurate, inexpensive reference frequency source good for most amateur and experimental needs but not the size, cost, and complexity of one of the more sophisticated standards then this may be your answer. Most crystal oscillators are reasonably stable if kept at a constant temperature so the first step to try is leaving the instrument on all the time or coming up with a homebrew temperature control. If it still drifts too much you may can upgrade to a temperature compensated oscillator. Simply take an off-the-shelf 2.5PPM (or better) TCXO with either a screwdriver adjustment slot or voltage control (TCVCXO or VCTCXO) and add a buffer / divider multiplier as necessary.

The TCXOs are available for as little as $2.00 surplus or $15 new. The 2.5PPM spec is over a specified temperature range so at or near room temp they are very stable. I have a counter using a little dip sized can 2.5PPM TCXO that from cold power on in the shack is routinely within +/- 0.1PPM. All I did was wrap a piece of 1/16" thick foam padding around the can to keep the temperature differential across the chip down as it warms up. Seem that the built-in temp compensation is pretty good if it is allowed to stabilize but not as good while changing.

Whether you use an existing piece of gear or adapt a TCXO the next hurdle is calibration. You can usually get within 50Hz or so by zero beating against WWV by ear but a better method is needed. The simple one chip TRF 10MHz WWV receiver described below makes calibration to .1 to .01 PPM (10^{-7} or 10^{-8}) quick, easy and reliable. I listened at random times day and night for a few days and 10MHz WWV is always there, usually with just a few feet of cliplead for an antenna. An outside antenna is recommended, however, to reduce the chances of calibrating to yourself and for the10 second stable periods needed for .01PPM.

BACKGROUND

Back in the 1960's I had a part time job after school in a two-way radio shop. My "Elmer", Harold Angel, taught me quite a bit including how to calibrate an oscillator (used to check transmit and receive frequencies) by zero beating it to a HF WWV station using a receiver, listening to the tones and watching the S meter. There was a varying amount of complication in the process (with an inversely proportional degree of confidence as to whether you had it "right") depending on the signal strength of WWV vs. your oscillator, noise, fading due to propagation, having to wait for a "tone" or "quiet" segment, etc. You did have your choice of frequencies to pick from to improve your odds.

I have been using the zero beat method ever since then to calibrate my bench standard – a WWII surplus 3MHz crystal oscillator inside a temperature stabilized vacuum thermos bottle. It will hold within a few parts in 10^7 and can be adjusted to better than 1 in 10^7. This is probably good enough for anything I really need. A summary of the zero beat method follows.

OSCILLATOR CALIBRATION USING ZERO BEAT METHOD

- This isn't really complicated enough to require a procedure but doing so will illustrate some of the possible pitfalls and help someone trying it for the first few times.
- Turn off all computers or other electronic equipment not involved in the measurement until you've done it once. Then you can turn it all back on and check for interference.
- Choose a WWV frequency (typically 10MHz) that can be received with relatively good strength at your location and which is the same frequency as your standard (typically 1 or 10MHz) or a harmonic (eg. 10MHz WWV will work for a 1, 2, 5, or 10MHz.)
- Tune in WWV in AM mode and note the S meter reading.
- Loosely couple the output from your standard to the receiver to get as much signal as you can without increasing the S meter more than ½ unit. The idea is to have WWV and your signal roughly the same amplitude. Hanging a clip lead off the output of the standard may be

enough or you may have to insert a "T" in the receiver antenna line and connect another clip lead to the center conductor of the T and bring the two clip leads close together.

- If your standard is more than 50 to 300z off frequency (depending on the bass response of your receiver and speaker) you will hear a "beat note" which is the frequency difference. Do not confuse this with the WWV transmitted tone or a BFO tone if you're using SSB mode.
- Adjust the frequency of your standard to make this beat note get lower in frequency and eventually become inaudible.
- Keep adjusting in the same direction and the note should reappear. Set the frequency adjustment approximately mid way between the two points where it is just audible.
- Look at the S meter. If you're lucky you'll see it fluttering or swinging back and forth. If not, adjust the frequency adjustment between the two points where the note disappears and watch the meter. If that doesn't work try increasing or decreasing the signal level from your standard and adjusting the frequency again.
- Once you see the meter swinging adjust the frequency until the swinging slows down and stops.
- If you can't see the S meter swinging (or don't have one…) you can, with a lot of practice, hear the zero beat as a warble in the tone transmitted by WWV or the BFO tone on SSB. This is somewhat tricky and you have to have an "ear" for it.

NEWER AND / OR MORE ACCURATE METHODS

A few years ago I got interested in building a WWVB (60KHz) standard. I had seen Rubidium and Cesium standards in my previous work life at Bell Laboratories and had heard about GPS based standards but these all seemed a bit much for what I wanted (too big, too complicated, too expensive, etc). I didn't really need a better standard but thought a WWVB standard would be a fun project. These are all available on Ebay and elsewhere for varying $$.

To make a long story short I got almost everything in the WWVB standard working but couldn't overcome the deep nulls in the signal every second. There was also the question of whether or not the signal would be usable only at night and/or only in the winter. I live on the east coast and the signal isn't so hot here to begin with. Anyhow, I decided to scrap the whole mess and not waste any more time on it.

EVOLUTION OF THE HF (10MHz) WWV RECEIVER / CALLIBRATOR

As I was putting the remains of the WWVB project on the shelf I thought of my brute force attempt at overcoming the nulls by adding a FM IF amplifier/limiter chip and some single crystal 60KHz filters. The amp was in an Altoids box. I had also ordered some 10MHz series resonant crystals with the thought of someday making a dedicated 10MHz receiver.

One of the problems with using the zero beat method is that you can't really tell what's going on as you approach the zero beat. Ideally the WWV signal and the standard signal should be exactly the same amplitude with no noise so that the sum would be 2X and the difference would be zero and produce the maximum meter swing. That's just one way to compare the phase of the two signals though. There is, for example, the 4046 but it also prefers a steady signal with constant amplitude and low noise.

What about using a nice ham or communications receiver? You can't just use the IF of a receiver because the WWV signal has already been mixed with an uncalibrated signal (the LO). You could use the same LO to also mix with the standard separately from the WWV mixer so that the errors would cancel out but that seemed like a lot of drudgery just to compare the phase of two signals.

What I ended up with was a high gain, narrow band TRF receiver for 10MHz WWV using a single chip with crystals instead of LC tuned circuits. It eliminates some, but not all, of the QSB (fading) but more importantly lets you directly compare the phase. By displaying the WWV and standard waveforms simultaneously on a dual trace scope there is no question about what's going on near zero beat. Some more gain, ALC, narrower bandwidth, etc. could be added but the brain cuts through the noise, fading and other confusion factors quite easily. If the signal disappears for a second or two the brain compensates. For .01PPM you do need 10 seconds of signal with no dropouts but this doesn't seem to be hard to get with an outside antenna. Any HF antenna will work. A VHF/UHF antenna may work if you just connect the center conductor and leave the shield open.

Sensitivity	2.3uV RMS for 5mVPP output
Overall Gain	Aprox 60dB
Bandwidth	-3dB 33Hz,-20dB 2KHz, -40dB 5.4KHz, -60dB 12.2KHz, 15KHz –90dB
Actual RSSI	-110dBm 0.7uV .434V
	-80dBm 23uV .602V
	-60dBm 230uV 1.902V
	-40dBm 2.3mV 2.77V
	-20dBm 23nV 3.58

NOTES ON THE CIRCUIT, COMPONENTS, ETC.

Mouser still has the 10MHz xtals 520-HCU1000-S for $.53 each (as of 8/10/2007). I would get 10. The crystals were a few hundred Hz high with 2-3K source and load Z but pretty much on freq with 50-200Ohms. I sacrificed a few more dB of insertion loss for not having to trim the crystals. The loss is about 10dB at center freq. The output XTAL filter is just to shape the waveform into a pretty sine wave. A high Q LC circuit should work just as well.

The null capacitors are tricky/touchy to adjust as any one of them is sufficient to get rid of almost all out-of-band signals so I short the other two when adjusting one. I nulled at 9.5 MHz but the freq probably doesn't matter.

The FM/IF/LIMITER chip is getting harder to find. The NE614/SA614 has separate amplifier and limiter sections and is rather straightforward. The only trick is that any significant load on the output (pin 9) kills the output. That's why it's buffered by a FET. There are a number of FM/IF chips that could be substituted (not pin-for-pin) but none that I've seen except for surplus.

I didn't have any problem with stability in the Altoid box but the thing will take off if given the opportunity (long clip leads, etc.)

When looking at the scope with sync on your oscillator/standard, the sine wave from WWV will slip at a rate equal to the difference in frequency. I doesn't matter what your oscillator ferquency is. If it's 1MHz there will be 10 cycles of WWV for one of yours. Count the number of WWV cycles that pass an edge of your waveform. One cycle slip per second is 1Hz. If you watch for 10 seconds and WWV moves 1 cycle then that’s .01PPM (10MHz * 10Sec = 10^8). If there's no movement at all or it's jerky check that you don't have leakage from your oscillator back into the antenna/receiver. It's not unusual to see WWV swinging back and forth a fraction of a cycle or the amplitude fading to zero momentarily due to band conditions.

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(put 10MHz WWV, your callsign or something to catch my eye so I'll pluck it from the spam filter)